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USABILITY EVALUATION OF UNMANNED AERIAL VEHICLE SYMBOLOGY

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14. ABSTRACT

Symbology to represent fixed-wing and rotary-wing Unmanned Aerial Vehicles (UAVs) was developed and compared to MIL-STD-1787C symbology. The symbology was evaluated in several simulated UAV operator tasks. In the first portion of the study, static screen-shots from a simulated UAV control station display screen were presented to participants. Participants were required to determine how many air vehicle symbols of a particular type or affiliation were present in the screen-shot. The results indicated that the new symbology was recognized at least as quickly and accurately as existing MIL-STD-1787C symbology. In the second portion of the study, participants monitored dynamic video on the control station display. Participants were required to monitor the display for specific events associated with their ownships. Again, performance with the new symbology was at least as good as that with MIL-STD-1787C symbology. While this study was limited in scope, the results represent a productive step in the development, evaluation, and standardization of new UAV symbology.

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SUMMARY

Symbology to represent fixed-wing and rotary-wing Unmanned Aerial Vehicles (UAVs) was developed and compared to MIL-STD-1787C symbology. The symbology was evaluated in several simulated UAV operator tasks. In the first portion of the study, static screen-shots from a simulated UAV control station display screen were presented to participants. Participants were required to determine how many air vehicle symbols of a particular type or affiliation were present in the screen-shot. The results indicated that the new symbology was recognized at least as quickly and accurately as existing MIL-STD-1787C symbology. In the second portion of the study, participants monitored dynamic video on the control station display. Participants were required to monitor the display for specific events associated with their ownships. Again, performance with the new symbology was at least as good as that with MIL-STD-1787C symbology. While this study was limited in scope, the results represent a productive step in the development, evaluation, and standardization of new UAV symbology.

Contents

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INTRODUCTION

The function of a symbolic representation is to convey information about a referent subject or situation. When selecting or developing a standard symbology set for use in the command and control of unmanned aerial systems (UASs), a driving factor in the selection or development process should be the degree to which the symbology set allows an operator to rapidly understand the referent subject or situation from the symbolic representations and maintain situation awareness.

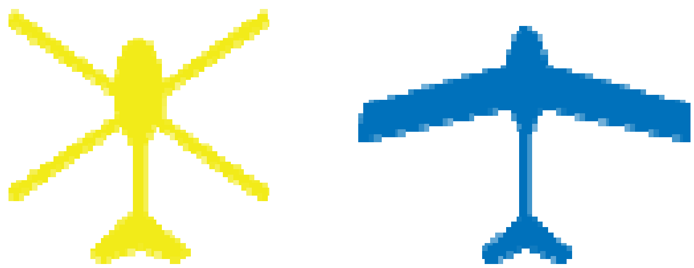
In developing a tactical display symbology set for UASs, one approach is to incorporate new UAS symbology into existing military standards. Two military standard (MIL-STD) symbology sets that represent air vehicle operations are MIL-STD-1878C and MIL-STD-2525B. MIL-STD-1787C details the symbolic representations to be used in aircraft cockpit interfaces. MIL-STD-2525B is a larger and much more general symbology set designed to function as a universal C4I class of symbols. As such, the focus of MIL-STD-2525B on aerial vehicles is limited to a symbolic representation of air vehicles within a larger battlespace environment. No “inside the cockpit” operations are captured within MIL-STD-2525B.

It is not entirely clear which standard has precedence for UAS operations. MIL-STD-2525B states that it “applies to all DOD components directly or indirectly involved with C4I operations, system operations, system development, and training within the context of warfighting operations, and that MIL-STD-2525B will serve as the standard symbol set for all future DOD uses of C4I symbology. The standard contains symbology that can be applied to mapping/charting, weather, cockpit display, and engineering design symbology to the extent that it is usable by these communities. The standard will apply to all future use of symbols in two dimensional and electronic display systems in C4I environments.” MIL-STD-2525 also states that “MIL-STD-1787C-Aircraft Display Symbology has been developed to provide standards guidance regarding rotary-wing and fixed-wing cockpit displays.” Furthermore, as noted in MIL-STD-1787C, “The tactical display symbology in this standard is to be used as an alternative to the symbology in MIL-STD-2525, which is not appropriate for aircraft use.” While the applicability of MIL-STD-1787C and MIL-STD-2525B suggests that MIL-STD-1787C may take precedence in aircraft cockpit display, it is not clear which document takes precedence for UAS control systems.

The choice between utilizing MIL-STD-1787C or MIL-STD-2525B as the symbology set for UASs is complicated by the variety of levels of control found in UASs, from man-in-the-loop remotely piloted vehicle type operations to completely or almost completely autonomous UAS operations. While MIL-STD-1787C holds obvious advantages for man-in-the-loop piloting operations, MIL-STD-2525B holds advantages for a UAS operator engaged primarily in information management other than that associated with direct piloting of an air vehicle.

It should be noted that there are limitations associated with both MIL-STD-1787C and MIL-STD-2525B in the context of UAS operations. Neither symbology set deals with a number of factors and concerns for UAS operations. For example, neither standard deals with the symbolic representation of multiple air vehicles under the control of a single operator. Given the limitations of both standards, the final symbology set for UAS operations will necessarily involve a significant modification of either MIL-STD-1787C or MIL-STD-2525B.

In evaluating the relative merits of MIL-STD-1787C versus MIL-STD-2525B, and in the development of new UAS symbologies, several issues should be considered including situation awareness, recognition speed, and errors associated with processing information. In the present study, a set of UAS symbols was developed for evaluation in the context of MIL-STD-1787C symbology. Symbols for both fixed-wing and rotary-wing unmanned air vehicles (UAVs) were created (see figure 1). The symbols were developed in accordance with the standard human factors criteria that the symbols must allow one to rapidly recognize the symbols and accurately distinguish the symbols from other related symbology. The symbols were then utilized and evaluated in several simulated UAS operator tasks. The aim of this study was to evaluate the degree to which these newly developed symbols could be effectively utilized within a larger MIL-STD-1787C symbology set for UAS operations.



a b

Figure 1: Examples of new UAV symbology developed for this study.
(a - Rotary-wing UAV, unknown affiliation; b - Fixed-wing UAV, ownship)

METHOD

PARTICIPANTS

Twenty male and female university students between the ages of 18 and 39 served as participants. The average age was 24. The study was approved by the institutional review board at East Central University, located near Ada, Oklahoma (approximately 65 miles southeast of Oklahoma City). All participants signed an informed consent statement prior to participating in the study.

TRAINING

Each participant was first given approximately 45 min of individual instruction and training prior to starting the evaluation. Training consisted of a tutorial session in which participants were given an explanation of UAVs, control stations, symbology, and air operations. Participants viewed a chart depicting MIL-STD-1787C symbology and the symbology developed for this study, static screen-shots from Open Unmanned Mission Interface (Open UMI) scenarios (see figure 2), and several videos of Open UMI scenarios. Open UMI is an existing vehicle control interface that allows for the simultaneous monitoring and control of multiple unmanned vehicles. Participants were then given an opportunity to review and study the symbology set in order to commit it to memory. The researcher provided clarification and explanation whenever participants requested it. At the completion of the training session, participants were given a brief test in order to ensure that they understood the symbology set and the Open UMI display. Participants were required to correctly identify 90% of symbols before proceeding to the evaluation phase. All participants reached the criterion of 90% accuracy after their first training session.

Figure 2: Example of an Open UMI scenario showing UAV symbology developed for this study, and MIL-STD-2525B symbology substituted for MIL-STD-1787C symbology. A copy of MIL-STD-1787C can be requested from ASC/ENOI, Wright-Patterson AFB, Ohio, 45433-7101.

EVALUATION

The quantitative human factors evaluation process entailed participants conducting rapid evaluations of events from the Open UMI tactical display. These static scenes and prerecorded video events involved UAS and non-UAS vehicles in varying levels of density and distribution about the display. Researchers collected data from participants in the form of latencies to perform recognition/identification tasks, errors in processing information about the scenarios, and the degree to which participants were able to develop and maintain situation awareness of the scenarios being presented. For each analysis, participants were presented with scenarios at three levels of air vehicle density, allowing an analysis of performance within sparsely, moderately, and heavily populated Open UMI scenarios.

RECOGNITION SPEED

During the Recognition Speed phase of the evaluation, participants were presented with static screen-shots from the Open UMI control station and were required to rapidly determine how many air vehicle symbols of a particular type or affiliation were present. For instance, participants were asked to rapidly determine how many bombers were present. The participants would then carry out this task on nine separate screen-shots. When completed, the participant would then move on to another class of air vehicles such as fighters or fixed-wing UAVs. Screen-shots varied in how densely populated the symbols were. Participants performed this task on nine screen-shots for each of the symbol categories listed below:

1. Friend
2. Foe
3. Neutral
4. Unknown affiliation
5. Ownship
6. Bomber
7. Helicopter
8. Cruise missile
9. Heavy
10. Fighter low tech
11. Fighter high tech
12. Fixed-wing UAV
13. Rotary-wing UAV
14. Unknown class

Thus, participants performed this task for 126 total screen-shots. Latencies to respond were recorded in milliseconds. The number of errors per screen-shot was also calculated.

RESULTS

LATENCIES

The results indicate that the latencies to recognize the new UAS symbols fell within the range of latencies to recognize symbols from MIL-STD-1787C (see table 1). That is, participants were as fast with the new UAS symbols as they were with the MIL-STD-1787C symbols. Latencies associated with affiliation (M = 1.670) were shorter than latencies for vehicle class (M = 3.592; $t(235) = 19.93$, $p < .001$). This is almost certainly due to the fact that color variations associated with affiliation symbology are much more salient attributes than complex shape variations associated with vehicle class symbology. We also compared whether the new "ownship" color (blue) was recognized as quickly as the existing MIL-STD-1787C affiliation colors. The latency to recognize ownship symbology (M = 1.685) was not statistically different than the latency to recognize other affiliations (M = 1.622; $t(34) = 0.12$, *ns*). There was also no statistically significant difference in the latencies to recognize the new UAV rotary-wing symbology (M = 3.849) compared to MIL-STD-1787C helicopter symbology (M = 3.792; $t(38) = 0.20$, *ns*). Additionally, there was no difference in the latencies to recognize the new UAV fixed-wing symbology (M = 4.099) compared to all other MIL-STD-1787C fixed-wing symbology (M = 3.719; $t(53) = 1.70$, *ns*).

Table 1: Latencies to Recognize Symbology

Latency (sec)	
Foe	1.459
Unknown	1.587
Neutral	1.601
Ownship	1.685
Friendly	2.035
Unknown class	2.582
Bomber	2.993
Heavy	3.315
Cruise missile	3.561
Helicopter	3.792
UAV rotary-wing	3.849
Low tech fighter	4.018
UAV fixed-wing	4.099
High tech fighter	4.528

ERROR ANALYSIS

Errors included the failure to recognize symbols or the misidentification of symbols. The results indicate that the number of errors with the new UAS symbols fell within the range of errors found with symbols from MIL-STD-1787C. That is, the number of errors associated with the new UAS symbols did not differ substantially from the number of errors associated with the MIL-STD-1787C symbols (see table 2). The number of errors for affiliation (M = .077) was

significantly less than the number of errors vehicle class (M = .150; $t(270) = 4.64$, $p < .001$). The number of errors associated with the new ownship color (M = .062) was not significantly different from the number of errors seen with colors associated with existing MIL-STD-1787C affiliation symbology (M = .080; $t(27) = 0.72$, *ns*). The number of errors associated with the new UAV fixed-wing symbol (M = .170) was not significantly different from those seen with existing MIL-STD-1787C fixed-wing symbols (M =.148; $t(21)$ = 1.02, *ns*). The number of errors associated with the new UAV rotary-wing symbol (M = .156) was significantly smaller than that associated with the existing MIL-STD-1787C helicopter symbol (M = .289; $t(38) = 2.55$, p <.05). For some symbols, the error rates were rather high. For example, the symbol for heavy aircraft had an error rate of 0.211, and that for helicopters was 0.289. One possible explanation is that participants were encouraged to make their assessments as quickly as possible. Therefore, perceived time pressure may account for some of the errors. Another explanation is that some of these symbols were similar and may have been difficult to distinguish. For example, the helicopter and rotary-wing UAV symbols were similar, as were the heavy and bomber aircraft (both with wide wingspans). A third explanation is that participants received limited training, so error rates are likely higher than would be seen with experienced and well-trained operators.

Table 2: Symbology Error Rates

Errors (per screen-shot)

Cruise missile	0.017
Ownship	0.062
Low tech fighter	0.067
Neutral	0.067
Unknown class	0.068
Foe	0.078
Unknown	0.078
Friendly	0.094
High tech fighter	0.151
UAV rotary-wing	0.156
Bomber	0.164
UAV fixed-wing	0.170
Heavy	0.211
Helicopter	0.289

Together, the results from the latency analysis and the error analysis indicate that participants were able to recognize and categorize the new UAV symbols with similar speed and accuracy as compared to existing MIL-STD-1787C symbols.

SITUATION AWARENESS ANALYSIS

During this second phase of the evaluation, participants monitored prerecorded videos of Open UMI scenarios and monitored when ownship UAVs entered and exited restricted airspace. They also monitored when alerts were presented and removed for the ownship UAVs. The alerts were presented as small symbols tagged to an air vehicle indicating problems with engines, communications, payloads, etc. (see figure 2); however, participants were not required to

differentiate between the various types of alerts. Rather, they simply had to note when an alert turned on and turned off.

When participants detected any of the four types of events, they were required to verbally call out the event they had detected. Each participant monitored three scenarios. Each scenario was 8 min in length. One scenario was sparsely populated with two ownship UAVs and, on average, seven other air vehicles. A moderately populated scenario had 3 ownship UAVs and, on average, 11 other air vehicles. A densely populated scenario had 5 ownship UAVs and, on average, 18 other air vehicles. The total number of UAV events ranged from 31 in the sparsely populated scenario to 66 in the densely populated scenario.

Measures of situation awareness included the latency to respond and correct identification of the prescribed events. A pilot study involving tracking non-UAV MIL-STD-1787C air vehicles was used to determine a performance benchmark from which success or failure could be measured in the present study. The pilot study involved tracking foe aircraft movements into and out of restricted airspace, as well as into and out of the on-screen viewing area during a densely populated scenario. In that pilot study, the average time to detect events was 2.93 sec, and 83% of events were detected. Using those numbers as guidelines, a response latency of 3 sec or less and detection of at least 85% of events was determined to be a reasonable performance benchmark for this type of task.

The situation awareness analysis results indicate that participants performed successfully relative to benchmark levels on the percent of events detected in each of the sparsely, moderately, and densely populated scenarios (see table 3). Additionally, participants performed successfully relative to benchmark levels for latency to respond in each of the three scenarios (see table 4). Together, these results suggest that the newly developed UAS symbology allowed for situation awareness slightly better than that found with the existing MIL-STD-1787C symbology in our pilot study.

Table 3: Percent of Events Detected by UAV Density

Percent of Events Detected	
Sparse	92.26%
Moderate	90.73%
Dense	86.89%

Table 4: Detection Latency by UAV Density

Latency to Respond (sec)	
Sparse	1.598
Moderate	1.847
Dense	2.059

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CONCLUSIONS

While this study was limited in scope, the results provide a clear indication that new UAS symbols can be successfully developed and incorporated into the existing MIL-STD-1787C symbology set. Additionally, the new symbols developed in this study could provide individual operators with the basic elements necessary for rapid identification and tracking of UAVs with appropriate levels of situation awareness.

While this evaluation provided evidence of basic utility and usability of a set of UAS symbols, additional evaluations of these symbols should be carried out using actual UAS operators. Furthermore, the tasks within the present study did not simulate a number of critical aspects of actual UAS operations. A more realistic simulation should be used for further evaluations of this particular symbol set.

Given the aforementioned limitations, this study represents a productive step in the development and implementation of a standard UAS symbology set.

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